ABSTRACT

The present thesis involves the study of introducing passive exit flexibility in a two dimensional starting jet. This is relevant to various biological flows like propulsion of aquatic creatures (jellyfish, squid etc.) and flow in the human heart. In the present study we introduce exit flexibility in two ways. The first method was by hinging rigid plates at the channel exit and the second was by attaching deformable flaps at the exit. In the hinged flaps cases, the experimental arrangement closely approximates the limiting case of a free-to-rotate rigid flap with negligible structural stiffness, damping and flap inertia; these limiting structural properties permitting the largest flap openings. In the deformable flaps cases, the flap's stiffness (or its flexural rigidity EI) becomes an important parameter. In both cases, the initial condition was such that the flaps were parallel to the channel walls. With this, a piston was pushed in a controlled manner to form the starting jet. Using this arrangement, we start the flow and visualize the flap kinematics and make flow field measurements. A number of parameters were varied which include the piston speed, the flap length and the flap stiffness (in case of the deformable flaps).

In the hinged rigid flaps cases, the typical motion of the flaps involves a rapid opening with flow initiation and a subsequent more gradual return to its initial position, which occurs while the piston is still moving. The initial opening of the flaps can be attributed to an excess pressure that develops in the channel when the flow starts, due to the acceleration that has to be imparted to the fluid slug between the flaps. In the case with flaps, additional pairs of vortices are formed because of the motion of the flaps and a complete redistribution of vorticity is observed. The length of the flaps is found to significantly affect flap kinematics when plotted using the conventional time scale L/d. However, with a newly defined time-scale based on the flap length (L/L_f), we find a good collapse of all the measured flap motions irrespective of flap length and piston velocity for an impulsively started piston motion. The maximum opening angle in all these impulsive velocity program cases, irrespective of the flap length, is found to be close to 15 degrees. Even though the flap kinematics collapses well with L/L_f, there are differences in the distribution of the ejected vorticity even for the same L/L_f.

In the deformable flap cases, the initial excess pressure in the flap region causes the flaps to bulge outwards. The size of the bulge grows in size, as well as moves outwards as the

flow develops and the flaps open out to reach their maximum opening. Thereafter, the flaps start returning to their initial straight position and remain there as long as the piston is in motion. Once the piston stops, the flaps collapse inwards and the two flap tips touch each other. It was found that the flap's flexural rigidity played an important role in the kinematics. We define a new time scale (t^*) based on the flexural rigidity of the flaps (EI) and the flap length (L_f). Using this new time scale, we find that the time taken to reach the maximum bulge ($t^* \sim 0.03$) and the time taken to reach the maximum opening ($t^* \sim 0.1$) were approximately similar across various flap stiffness and flap length cases. The motion of the flaps results in the formation of additional pairs of vortices. Interestingly, the total final circulation remains almost the same as that of a rigid exit case, for all the flap stiffness and flap lengths studied. However, the final fluid impulse (after all the fluid had come out of the flap region) was always higher in the flap cases as compared to the rigid exit case because of vorticity redistribution. The rate at which the impulse increases was also higher in most flap cases. The final impulse values were as large as 1.8 times the rigid exit case. Since the time rate of change of impulse is linked with force, the measurements suggest that introduction of flexible flaps at the exit could result in better propulsion performances for a system using starting jets.

The work carried out in this thesis has shown that by attaching flexible flaps at the exit of an unsteady starting jet, dramatic changes can be made to the flow field. The coupled kinematics of the flaps with the flow dynamics led to desirable changes in the flow. Although the flaps introduced in this work are idealized and may not represent the kind of flexibility we encounter in biological systems, it gives us a better understanding of the importance of exit flexibility in these kinds of flows.